

## ASSESSING QUALITY AND QUANTIFICATION OF MUNICIPAL SEWAGE INFLOW INTO MANCHALAPUR TANK BASED ON PER CAPITA WATER CONSUMPTION AND RUNOFF ESTIMATION

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### ABSTRACT

*With growing concerns in India to curtail tank pollution load, such approach must have initial processes of quantifying inflow into tank and assessing their quality to inform any real-time decision making. In this study, the Manchalapur tank system, a disposal point of sewage from Raichur was considered. The inflow into the tank system was considered to be both sewage and stormwater from the catchment of the tank. Hence, in quantifying the inflow, the per capita water supply of Raichur City was studied to estimate the sewage flowrate, and SCS curve number employed in estimating the rainfall runoff. During the rainy days, at expected dilution rate of 18.8% by stormwater, tank water degradation was minimal as compared to the pre-monsoon season when tank water was found unsuitable for reuse (as evidenced by Water Quality Index values). It is concluded that the sewage being received from Raichur city be treated before discharging into the tank. The results also straddle stakeholders including CMC to seek emerging and alternative technology to curtail any and such tank pollution within threshold.*

**KEYWORDS:** Water Quality Index, Pollution Load, Tank System, SCS Curve Number, Water Supply, Manchalapur, Raichur City

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### INTRODUCTION

The United Nations' new pact of Sustainable Development Goals has gained the centre stage and subject of discussion in the public domain. In furtherance are several interventions for their successful achievement by the end of 2030. It is a considered fact that improvement of agricultural productivity is key in achieving the SDGs poverty alleviation and zero hunger by 2030 in developing countries as agriculture is the backbone of the economy of many developing countries. But this is continuously being threatened by various environmental challenges; among them are better management of fresh water quality and increased stress on surface water sources for agricultural production (Kamyotra and Bhardwaj, 2011). Water is the lifeblood for all human activities, but this valuable resource is increasingly being stressed as human populations grow and demand more water of high quality for both domestic purposes and economic activities.

In the face of this seemingly never ending challenge for water resource among the various sectors demand for judicious use of water, multiple use of water and human interventions in the management of water for agriculture from alternative sources. One such intervention may be the management and reliance on irrigation tank systems for safe reuse for agricultural purposes.

A tank in this context is a simple rainwater harvesting structure designed by early Indian settlers using indigenous methods. According to Shanmugham (2007), out of the 500,000 irrigation tanks that exist in India, 150,000 are found in the semi-arid region of Deccan plateau. They are located in hydrologically favourable sites, some of them in sequential chains or cascades, effectively capturing the rainfall and serving multiple uses with irrigation having the major share. These historical tanks have been one of the most important water resources on which the rural communities depend for their livelihood. However, over the past decades, most of these tanks are becoming less efficient as they are subjected to different forms of degradation of which urban sewage disposal stands to be of greater mention. As per the Indian Central Pollution Control Board (CPCB, 2010), it is estimated that about 38,254 million litres per day (MLD) of wastewater is generated in urban and peri-urban centres of the country. However, the municipal wastewater treatment capacity developed so far covers only about 31 per cent of wastewater generation in the urban and peri-urban centres of India. Thus, the disposal of untreated sewage into water bodies including traditional tank systems under urban environments of the India nation has been protuberant over many years now.

With freshwater either unavailable or too expensive, and wastewater treatment not keeping up with urban growth, urban farmers often have no alternative but to use highly polluted water (Buechler *et al.*, 2002; Bhamoriya, 2004; Minhas and Samra, 2004; Hofstedt, 2005; Huiberset *et al.*, 2005; Rutkowski *et al.*, 2007; Kaur *et al.*, 2012; Amerasinghet *et al.*, 2013). The India traditional irrigation tank systems which are mostly disposal points of urban sewage, mostly untreated, are being considered on the regional scale to curtail its pollution level within permissible limits to pose no inter alia threats on irrigation usage. Any of such interventions must consider a diagnostic analysis on the considered tank system – where assessment of tank water quality and quantification of inflow being the primary steps. Due to increase in urban population and thus a direct increment in sewage load year after year, quantification of sewage inflow must consider in its estimation the per capita water consumption of the city (as according to the Central Public Health and Environmental Engineering Organisation, 80% of water supply returns as sewage) and rainfall-runoff as the components of urban sewage inflow (Tchobanoglous *et al.*, 2004).

The Manchalapur tank system located about 10 km away from Raichur city in the Karnataka state of India, is a typical tank system being subjected to heavy inflow of municipal sewage and provides irrigation for about 786 hectares of agricultural land. And hence was considered for this study with results expected to serve as primary data on the tank system as prerequisite for remedial strategy. The approach followed could form the basis and be ritualised in diagnosing other tanks or lakes with similar scenario. Hence, this study sought to investigate the status of quantity and quality of the Manchalapur tank water under the consideration of current municipal sewage inflow apart from the runoff from the catchment with the objectives of quantifying the inflow pattern into the tank system due to runoff and municipal sewage and release water quality parameters and its suitability for safe reuse for agricultural purpose.

## METHODOLOGY

### Study Area

The Manchalapur tank system spreads adjacent to the Manchalapur village and located at about 10 kilometres (km) away from the Raichur city of the Karnataka state of India. The area of investigation spreads around 981 hectares (ha) including its catchment, command and water spread area. Manchalapur is situated in the north-eastern dry zone (Zone-2) of Karnataka located at 16° 14'N latitude and 77° 19'E longitude and at an elevation of 380 metres above mean sea level. Average annual rainfall of the area is 630 mm. Monthly mean maximum and minimum temperature of 39.3 °C and 9.7 °C are recorded in April and December respectively.

The tank system, even though, bestowed with varied soil texture, the total area could mainly be classified into vertisols (80 per cent) and red sandy loam soils (15 per cent). The tank system mainly consists of agricultural land (786 ha) including command area which constitutes about 80 per cent of total catchment area, followed by sizable area (10.2 per cent) under waste land (100 ha), social forest (25 ha), rock outcrop (35 ha), and its own water spread area (35 ha) representing 3.57 per cent of catchment area.

### Per Capita Water Supply of Raichur City

The Raichur city is more or less situated midway between two popular rivers in the state. The TungaBhadra River is situated 30 km on the south and Krishna River 22 km on the north. Being located in the arid and hot zone of the state with very low intensity of rainfall the reliability of ground water is found not sound. Hence, there is no alternative than to rely on either of the rivers. It was based on this fact that Krishna River was selected for the water requirement of the city as per the City Municipal Corporation. River intake arrangements were made for the extraction of raw water from the Krishna River. The second stage water supply was executed with the TungaBhadra canal due to the proximity of the canal. But due to the canal closures and other arrangements for irrigation it was found that impounding reservoirs were necessary which involved excess pumping of water to meet evaporation losses also. Hence, the third water supply was executed with Krishna River, a perennial source. These three water supply schemes are currently producing 2.27 MLD, 10 MLD and 30 MLD respectively. Therefore, the total quantity of water supplied in the city via these three schemes is about 42.27 million litres per day (mld) which eventually translates into circa 167 litres per capita per day (lpcd) including system losses for the present population of 252,115 (projected). This is the gross supply at source. However, accounting for CMC's distribution losses which are perked approximately at 19 per cent, the per capita water supply of Raichur city is estimated to be 135 lpcd at consumer end.

### Projected Population and Sewage Generation

Sewage flowrates may be derived from analysis of population and estimates of per capita wastewater from similar communities. It is also a widely accepted approach to relying on water consumption records in estimating the wastewater flowrate ((Tchobanoglou *et al.*, 2004). Population projection and sewage generation were calculated and the probable increase in population growth estimated using the trend line 3<sup>rd</sup> order polynomial method as employed by the City Municipal Corporation (CMC) considering 1901 as the base year.

$$Y_n = 170x^3 - 300x^2 - 260x + 23,950 \quad (1)$$

where,  $Y_n$  is the projected population for year 'n',  $x$  is the number of decades from the base year (1901), including the base year. For example (2014 - 1901)/10 + 1 gives 12.3 as  $x$  value.

This was estimated for the various wards of the city and their respective sewage generation estimated.

### Quantification of Inflow into the Tank

The components that make up the sewage flow from the Raichur city into the Manchalapur tank depend on domestic wastewater and runoff resulting from rainfall. The principal sources of the domestic wastewater are the residential areas, and other institutional and recreational facilities. The sewage flowrate was derived from analysis of population data and estimates of per capita water supply of the Raichur city. Runoff resulting from rainfall which eventually contributes to inflow into the tank was estimated by using the SCS curve number method according to USDA (1972).

### Estimation of Runoff from the Catchment Resulting from Rainfall

Surface runoff is mainly controlled by the amount of rainfall, initial abstraction and moisture retention of the soil. The probable runoff estimation into the tank system was estimated from rainfall data of the area sourced from the University of Agricultural Sciences, Raichur's Main Agricultural Research Station and estimated using the SCS-CN method with considerations of the initial abstraction and moisture retention of the soil. The SCS-CN method originally constitutes the water balance equation and two fundamental hypotheses stated as, ratio of the actual direct runoff to the potential runoff is equal to the ratio of the actual infiltration to the potential infiltration, and the amount of initial abstraction is some fraction of the potential infiltration. Considering an initial abstraction as  $I_a = 0.2S$ , the runoff was estimated as:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (2)$$

where  $S$  is the potential infiltration after the runoff begins and it is given by following equation;

$$S = \frac{25400}{CN} - 254 \quad (3)$$

where  $CN$  is Curve Number and estimated using antecedent moisture condition and the hydrological soil group.

$$CN = \frac{\sum(CN_i \times A_i)}{A} \quad (4)$$

where  $CN$  is the weighted curve number,  $CN_i$  is the curve number from 1 to any number  $N$ , and  $A_i$  is the area with curve number  $CN_i$ .

### Estimation of Sewage Load into the Tank

For computing the sewage contribution from Raichur city into the tank, the projected population, the water supply available from the existing scheme and from the programmed augmentation scheme, expected infiltration were taken into consideration for computing the quantum of sewage inflow into the tank. The contribution from the commercial and public institutions was also taken care of in the equations for computing the sewage inflow.

Adopting a per capita water supply of 135 lpcd at consumer end as per guide lines (CMC, 2011) and 80 per cent of water supply returns as sewage as per CPHEEO norms, a per capita sewage contribution from Raichur city was adopted while making a provision for infiltration. Hence, in this study, the total unit sewage flowrate was estimated as 80 per cent of total net daily per capita water supply both from the existing, proposed water supply system and from the local sources (135 lpcd), and addition of expected infiltration assumed to be 2 per cent of sewage contribution.

With the flowrate estimated, the quantum of sewage contribution from households was estimated as a product of the total unit flowrate per capita and the projected population. However, due to the defunct nature of the sewerage system of the Raichur city, the Eklaapur STP which disposes sewage into the tank system receives only about 15 per cent of the total sewage contribution from households and disposes same (untreated) into the tank. The quantum of sewage inflow into tank was therefore estimated using equation (9).

$$\text{Quantum of sewage inflow} = \sum_{i=1,2,\dots,k}^n Q_i P_i \times 0.15 \quad (5)$$

where,  $Q_i$  is total unit flowrate and  $P_i$  is the projected population of a particular ward.

### Assessment of Tank Water for Quality Analysis

The inflow which consists of both sewage and runoff tend to degrade the tank water quality. Hence, water samples were drawn from the inlet of the tank, two locations in the water spread and outlet and tested for the physical, chemical and biological parameters of irrigation water per guidelines. Samples were collected from the tank on a seasonal basis, viz., pre-monsoon season (March-May), monsoon season (June-October) and post-monsoon season (November-February), for the year 2014/2015. After processing the samples were analysed for various physico-chemical parameters such as pH, EC, TS, TDS, TSS,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{PO}_4^{3-}$ , TKN,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , BOD, COD, surfactants and coliform analysis as per standard methods prescribed by APHA (1998). The water quality indices were calculated according to the methods suggested by Tiwari and Ali (1988). These indices (SAR, SSP, KR, and MR) were calculated according to following equations;

$$\text{Sodium Absorption Ratio (SAR)} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \quad (6)$$

$$\text{Soluble Sodium Percentage (SSP)} = \frac{100 (\text{Na}^+ + \text{K}^+)}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)} \quad (7)$$

$$\text{Kelley's Ratio (KR)} = \frac{\text{Na}^+}{\text{Ca}^{2+} + \text{Mg}^{2+}} \quad (8)$$

$$\text{Magnesium Ratio (MR)} = \frac{100 \text{Mg}^{2+}}{(\text{Ca}^{2+} + \text{Mg}^{2+})} \quad (9)$$

Results were compared to Central Pollution Control Board (CPCB) and Bureau of India Standards (IS 2296:1992) water quality requirements for suitability of irrigation.

This initial approach of estimating the constituent load of tank water was followed by estimating the influence of runoff on the contaminants for the three distinct seasons. This dilution of tank water was estimated as the ratio of estimated runoff to expected sewage inflow into the tank and expressed in percentage.

$$\text{Dilution ratio} = \frac{\text{estimated runoff}}{\text{expected sewage inflow}} \times 100 \quad (10)$$

## RESULTS AND DISCUSSIONS

The Manchalapur tank located at the outskirt of Raichur city has the total capacity of 677,740 cubic metres. The water resources of this tank are inevitable for domestic purpose of the Manchalapur village and a larger portion of the storage reservoir is used for irrigation. The Manchalapur tank apart from the runoff generated from its own catchment area of 981 hectares, receives substantial quantity of sewage from Raichur city. Hence, it was observed that the tank system

never gets emptied as large quantity of sewage is received throughout the year. However, this sewage not only adding to the probable runoff quantity but also causing the deterioration in the quality of stored water in its water spread area (35 hectares).

### Quantity of Inflow and Dilution of Tank Water

In an attempt to establish a holistic diagnostic analysis on the tank system, quantity of inflow was estimated for the past decade to give a clear picture of how the tank water is being degraded over the years and results presented in Table 1.

**Table 1: Comparison of Quantity of Runoff and Sewage Received by the Tank System for the Past Decade (2005 – 2014)**

Year	Annual Rainfall (mm)	Annual Runoff		Annual Sewage Production (m <sup>3</sup> )	Tank Water Dilution (%)
		Depth (mm)	Volume (m <sup>3</sup> )		
2005	935.6	186.797	1,832,478.57	9,389,479	19.52
2006	572.8	72.943	715,570.83	9,629,335	7.43
2007	928.9	131.029	1,285,394.49	9,873,621	13.02
2008	609.9	35.997	353,130.57	10,122,426	3.49
2009	936.3	331.393	3,270,585.33	10,375,781	31.52
2010	637.6	19.513	191,422.53	10,633,729	1.80
2011	353.1	31.132	305,404.92	10,896,308	2.80
2012	342.2	5.621	55,142.01	11,163,547	0.49
2013	729.9	66.136	648,794.16	11,435,523	5.67
2014	875.3	224.114	2,198,558.34	11,712,237	18.77

The maximum rainfall as received in the year 2009 (936.3 mm) and the minimum during the year 2012 (342.2 mm) had corresponding runoff estimated using SCS-CN method as 3,270,585 m<sup>3</sup> and 55,142 m<sup>3</sup> respectively. The sewage flowrate was estimated to be 110 lpcd and the monthly volume of sewage reaching the tank varied depending on increase in the projected population from year to year. The annual sewage volume during the period 2005 to 2014 increased from 9,389,479 m<sup>3</sup> to 11,712,236.8 m<sup>3</sup> indicating a decadal rise of about 24.7 per cent. This increase trend would be expected to continue as projected population growth observed is 13.3 per cent.

The table also shows that the runoff as a per cent of sewage quantity varied from 0.49 per cent (2012) to 31.52 per cent (2009). During the years with higher quantity of runoff (2009) the dilution rate was as high as 31.52 per cent. It can also be interpreted that during the period of 10 years, maximum runoff addition is about 31.52 per cent and this type of trend would in future cause higher salt concentration in the water spread area and tank becomes a maturation pond; since in all years during 2005-2014, the sewage inflow quantity exceeds the storage capacity of tank (677,740 m<sup>3</sup>). Further, it was observed that in recent years the tank never gets totally emptied in storage volume even during the summer which shows that almost all the sewage produced every year along with runoff gets detained partially during non-monsoon periods and subsequently gets pushed to downstream tank known as the Marched tank.

Considering the estimated population growth of 13.3 per cent annually, the corresponding sewage volume could be projected to be swelling by 24.74 per cent by 2045. It could be anticipated that in that next 30 years, total sewage volume generated could be 22,872,772 m<sup>3</sup> or more and surpass the volume of the tank. This situation would lead to lesser dilution of sewage by rainfall runoff and eventually produces a much degraded water quality. The dilution ratio between

sewage inflow and runoff was highest during the year 2009 (31.52 per cent) and was low during the year 2012 (0.49 per cent). However, in future that being projected up to next 30 years, at any point in time the dilution ratio would certainly be lesser than the recorded in 2009 due to higher expected sewage contribution to runoff. This shows that the present concentrations (physical, chemical and biological material) of tank water would be increasing as accentuated with caution to the planners to cater alternative solutions so that the degradation of tank would not further extend drastically.

### **Physico-Chemical Characteristics of Tank Water**

The tank water combined with sewage and runoff could be varying in quality with season. The quality of water in the water spread would also be changing due to mixing and detention of sewage for sufficient time in the tank. Hence, samples were drawn from the inlet, two different locations in tank water spread and outlet of the tank in three distinct seasons (pre-monsoon, monsoon and post-monsoon seasons) and the results presented in Table 2 (*appendix*).

The colour of the tank water appeared light brownish to light greenish. When the flow of water was low it appeared light brownish colour at the inlet and light greenish colour at the outlet and tank water storage proper. The greenish colour is a clear indication of the high productivity of the tank water ecosystem; thus, the presence of the excessive amount of nutrients in the water and consequentially increase the amount of phytoplankton productivity in the water. The brownish colour could be but indication of the presence of the colloidal particles in the water (Varunprasath and Daniel, 2010). The tank water has earthy odour and a cloudy especially at the time of sewage inflow. With lapse of time, due to microbial action, tank water darkened in colour and the smell of the sewage become more pronounced.

Water with high salinity is toxic to plants and poses a salinity hazard. The salinity indicators namely pH and EC were measured in three distinct seasons which eventually were influenced by the change in evaporation rate. As a result of change in temperature (21.8-39 °C) in pre-monsoon season, there was a substantial decrease in the dilution of sewage. This, however, increased due to runoff ingress during monsoon season and got stabilised during post-monsoon season. The observed pH across the seasons and locations in water spread indicated a marginal increase (7.68-8.39) during pre-monsoon as compared to monsoon season. The corresponding significant increase in EC in pre-monsoon season (1.53 dS m<sup>-1</sup>) from monsoon season (1.47 dS m<sup>-1</sup>) to post-monsoon season (1.14 dS m<sup>-1</sup>) as recorded. There are, however, moderate limitations for use of irrigation water of EC above 1.51 dS m<sup>-1</sup> in which case leaching would be required at higher range to curtail its effect on crop productivity. There is an increasing tendency in TDS values in the pre-monsoon season as compared to the monsoon season and post-monsoon season as TDS values range from 430-992 mg/l.

The prevalence or ionic abundance in tank water showed an increasing tendency from the wet seasons to the dry season. Higher dissolved ions during the pre-monsoon season, followed by post-monsoon and monsoon season which is corroborated by EC and TDS explain the increasing tendency of ions. Lesser water volume and higher dissolution of salts from bed rocks could also be attributed to the increasing tendency of ions in the pre-monsoon season. During the pre-monsoon season when tank received undiluted and concentrated sewage, Cl<sup>-</sup> was found to be the highest (511 mg/l), followed by post-monsoon season (451.25 mg/l) and the lowest in monsoon season (352.5 mg/l). The higher concentration of Cl<sup>-</sup> in the pre-monsoon season is perhaps due to inflow of human excrement and to the evaporation of tank water which, however, decreased in the monsoon season as a result of dilution of tank water. Although Cl<sup>-</sup> is essential to plants in very low amounts, it can cause toxicity to sensitive crops at high concentrations. The results obtained showed that, the chloride ion content is below the maximum permissible limit of irrigation water. However, irrigation water is only suitable for all plants when chloride concentration is below 70 mg/l (Bauderet *et al.*, 2014). Hence, selection of plant should be those that are

less sensitive of  $\text{Cl}^-$  effects.  $\text{SO}_4^{2-}$  is a major contributor to salinity in many irrigation waters.  $\text{SO}_4^{2-}$  in irrigation water also has fertility benefits. The recommended maximum permissible limit of sulphates ion in irrigation water is 1000 mg/l. From the results thus obtained,  $\text{SO}_4^{2-}$  was below the maximum permissible limit at all sampling locations in all three sampling seasons.  $\text{SO}_4^{2-}$  was recorded the highest in the pre-monsoon season (102.5 mg/l), followed by the post-monsoon season (100.25 mg/l) and the lowest in the monsoon season (81.25 mg/l) as a result of sewage dilution. Alkalinity concentrates of water samples was estimated and expressed as the sum of  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$ . High alkalinity causes  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  to form insoluble minerals leaving  $\text{Na}^+$  as the dominant ion in solution. From the results, alkalinity was high in the pre-monsoon season (8.5 mg/l) relative to that recorded in post-monsoon season (7.55 mg/l) and the least in monsoon season (7.4 mg/l). And this also reflects in the higher concentration of  $\text{Na}^+$  (28.25-122 mg/l) over both  $\text{Ca}^{2+}$  (65.25-74.5 mg/l) and  $\text{Mg}^{2+}$  (12.5-20 mg/l). And hence, high SAR values were also recorded which poses the problem of sodium hazard.

From the results, the average  $\text{BOD}_5$  was found to be the highest in monsoon season (213 mg/l), followed by pre-monsoon season (165.35 mg/l) and the lowest in the post-monsoon season (163.75 mg/l).  $\text{BOD}_5$  recorded the highest in the rainy season because of high rate of decomposition of organic matter which tends to quickly deplete the oxygen concentration, and this got stabilised during the post-monsoon season. However, it soared slightly high in the pre-monsoon season due to inflow of concentrated sewage. The corresponding COD values, however, recorded the highest in the pre-monsoon season (1060.25 mg/l) due to less dilution as compared to post-monsoon (488.50 mg/l) and monsoon season (394.50 mg/l).  $\text{BOD}_5$  values were below maximum permissible limit of water for irrigation purpose. However, the tank is also a source for propagation of fisheries which enjoys a good market in the Raichur city and other parts of the Karnataka state. According to the CPCB water quality criteria for propagation of wild life and fisheries, the recommended  $\text{BOD}_5$  of water should be 2 mg/l or less. From the results, high  $\text{BOD}_5$  coupled with very high COD render the tank water unsupportive for aquatic life. Fish mortality was observed at the inlet of the tank on an occasion in the pre-monsoon season. And this could be due to low oxygen content of tank water and nutrients build-up.

Nitrogen is an essential nutrient for biological development of all major organisms and it was estimated as Total Kjeldahl Nitrogen (TKN). TKN recorded in this study ranges from 27.78-53.17 mg/l and this obviously had resulted in the excessive growth of algae in the tank. The results also showed that the level of TKN of tank water was a better option to boost nutrient content of soil (Bauderet *et al.*, 2014). Phosphorus is not toxic but excessive discharge into aquatic environments can result in excessive algae growth, eutrophication and the depletion of oxygen in water bodies, impacting aquatic life. The average phosphates values recorded in this study varied from 12.25 mg/l (pre-monsoon season), followed by monsoon (14.84 mg/l) and highest in post-monsoon season (26.39 mg/l). The concentration of  $\text{K}^+$  varied from 19.25-42.98 mg/l. Easy solubility is responsible for NPK finding their way into water from animal waste, runoff from agricultural land due to fertiliser use, and detergent-filled domestic sewage of Raichur city (Andaet *et al.*, 2001). Less fertiliser use in the pre-monsoon season, coupled with high decomposition of organic matter in tank water resulted in lowest values of NPK recorded in the pre-monsoon season. High organic matter and high runoff from agricultural land due to fertiliser use and high decomposition of organic matter in tank water explain why NPK recorded higher in monsoon season than in pre-monsoon season. Albeit, the highest NPK was recorded in the post-monsoon season where there might likely be high fertiliser use and low decomposition of organic matter in tank water.

Surfactants are widely used in Raichur household products. Surfactant (Linear Alkyl Sulfonates) was recorded highest in the monsoon season ( $4.425 \pm 1.98$  ppm) and this was due to high runoff of surfactants product into tank.



Surfactants in the range of 1-100 ppm could have negative effects on aquatic life and results showed that surfactant was a major contaminant of tank water which contributed to impair aquatic life. Results of total coliform and faecal coliform organisms varied from 900 MPN/100ml to greater than 1600 MPN/100ml in the three sampling seasons. This variation is due to the fact that, coliforms are living organisms and they do not simply mix with the water and float straight downstream. Instead they multiply quickly when conditions are favourable for growth, or die in large numbers when conditions are not. Although during monsoon, rains washed more faecal matter from Raichur city into the tank, but cool water temperatures might have caused a major die-off. Likewise exposure to sunlight might have had same effect, even in the warmer water of summertime. On impact on aquatic life, faecal material adds excess organic material to the tank water. The decay of this material depletes the oxygen concentration of water and this lowered oxygen may impede aquatic life.

### Tank Water Quality Assessed by Water Quality Indices

The values of SAR, SSP, KR and MR were calculated in order to assess the suitability of tank water for irrigation. In assessing suitability of water for irrigation,  $\text{Na}^+$  concentration tend to be of importance as evident in the water quality indices (Kelley, 1951). The average values for these parameters are given in the Table 2.

**Table 2: Average Values of Considered Water Quality Indices of Tank Water and its Status for Irrigation**

Parameter	Pre-Monsoon Season	Monsoon Season	Post-Monsoon Season	Status for Irrigation
SAR	17.77	4.33	9.32	0-10 Excellent 10-18 Good 18-28 Fair >28 Poor
SSP	59.92	44.0	56.50	<50
KR	1.29	0.33	0.75	<1.0
MR	21.16	21.76	16.08	<50

According to Kelley (1951) excess of  $\text{Na}^+$  ions in water reacts with soil to reduce its permeability. High values of  $\text{Na}^+$  are hazardous to the crops. Therefore SAR is used for assessing the quality of irrigation water. Irrigation water is classified by Richards (1954) based on the values of SAR given in Table 3. Based upon above classification, the tank water is considered to be moderately safe for irrigation (SAR = 17.77) in the pre-monsoon season, convincingly safe for irrigation (SAR = 4.33) in the monsoon season since the concentrated sewage inflow is diluted by storm water in the rainy days. After rains have ceased in the post-monsoon season,  $\text{Na}^+$  concentration build-up begins and tank water could still be used for irrigation (SAR = 9.32) however with appropriate management. Tank water must therefore be treated for  $\text{Na}^+$  for causing less harm to crops especially in the pre-monsoon seasons. If the value of SSP for water is less than 50, it is suitable for irrigation (Wilcox, 1948). The values of SSP were estimated to be 59.92, 44.0 and 56.50 for pre-monsoon, monsoon and post-monsoon seasons respectively. Hence, tank water was found only suitable for irrigation purpose in the monsoon season. The average values for KR is found to be 1.29, 0.33 and 0.75 for pre-monsoon, monsoon and post-monsoon seasons respectively. Therefore by Kelley's ratio, tank water was not at all suitable for irrigation in the pre-monsoon season, and only quite fair in the post-monsoon season. High values of  $\text{Mg}^{2+}$  will adversely affect the crop yield because it makes the soil alkaline and also causes phototoxic effect on plants. The average values of MR are found to be 21.76, 21.16 and 16.08 for monsoon, pre-monsoon and post-monsoon seasons respectively; which indicate that tank water will not inflict on the soil the harmful effects of  $\text{Mg}^{2+}$  build-up and can be used for irrigation (Venkateswaraet. al., 1994). With the results of these water quality indices, it can be concluded that the tank water must be treated before to give a convincing reliance for irrigation usage.

## CONCLUSIONS

The results thus obtained from the physico-chemical analysis of tank water proved that tank water in most cases pose threats to impair aquatic life and was found not suitable for irrigation especially in pre-monsoon seasons. During the rainy days (monsoon) when tank water had experienced a dilution of about 18.8 % by rainfall runoff, degradation of tank water was mostly within threshold. However, degradation of tank water quality is anticipated to worsen in the future as population of Raichur city is expected to increase. Increase in population, however, augments pressure on water resources and therefore there is the need for alternative source of water for agricultural purposes. Dependence on sewage would be a win-win situation; aiming at ensuring optimal irrigation water-use plan for sustained crop production by minimising the risk of polluting tank water by preventing direct sewage inflow and identifying low cost – low energy wastewater pre-treatment processes and employing suitable separation distances for irrigation. In order to prevent adverse health impacts on public and animal, training and awareness programmes for farmers on water use are to be launched and practised. It is also recommended that future studies must take into account efforts to analyse water and fish samples for traces of metals.

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## APPENDICES

**Table 3: Range and Mean Values of Physico-Chemical Parameters of Manchalapur Tank Water and Limit for Irrigation Purpose**

Parameter	Pre-Monsoon		Monsoon		Post-Monsoon		Limit Prescribed by IS for Irrigation
	Range	Mean	Range	Mean	Range	Mean	
pH	7.23-8.72	8.39	7.23-8.21	7.68	7.01-8.64	7.88	5.5-9.0
EC (dS m <sup>-1</sup> )	1.45-1.72	1.53	1.36-1.66	1.47	1.06-1.32	1.14	2.25
TDS (mg/l)	796-1236	992	360-560	430	400-720	535	2100
TS (mg/l)	1304-1484	1401	600-800	670	640-800	715	-
TSS (mg/l)	216-688	409	200-280	240	80-240	160	600
Cl <sup>-</sup> (mg/l)	360-592	511	302-411	352.5	398-489	451.25	1000
SO <sub>4</sub> <sup>2-</sup> (mg/l)	88-110	102.5	79-84	81.25	81-123	100.25	1000
Alkalinity (mg/l)	7.4-9.8	8.5	7.2-7.6	7.4	6.4-8.8	7.55	-
PO <sub>4</sub> <sup>3-</sup> (mg/l)	8.23-16.37	12.25	2.25-34.68	14.84	20.4-35.48	26.39	-
TKN (mg/l)	21.85-38.23	27.78	38.4-65.42	51.49	40.98-68.53	53.17	-
K <sup>+</sup> (mg/l)	17.75-22.03	19.25	36.8-25.92	39.08	41.6-43.9	42.98	-
Na <sup>+</sup> (mg/l)	108-136	122	26-32	28.25	51-65	58	60
Ca <sup>2+</sup> (mg/l)	67.2-88	74.5	53.2-79	67	58-73	65.25	-
Mg <sup>2+</sup> (mg/l)	17.28-26	20	13.68-25.92	18.63	9.28-18.0	12.5	-
BOD <sub>5</sub> (mg/l)	136.8-192.8	165.35	205-232	213	156-178	163.75	350
COD (mg/l)	220-1586	1060.25	304-446	394.5	406-559	488.5	-
Surfactants (ppm)	2.2-5.5	3.15	2.9-7.2	4.43	1.0-7.0	3.28	-
Total coliform (MPN/100ml)	1600 - >1600	-	1600 - >1600	-	1600 - >1600	-	-
Faecal coliform (MPN/100ml)	900 - >1600	-	900 - >1600	-	900 - >1600	-	-

